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Title: METHOD AND APPARATUS FOR INK JET PRINTING ON RIGID PANELS

SPECIFICATION

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METHOD AND APPARATUS FOR INK JET PRINTING ON RIGID PANELS

This application is a continuation of Application Serial No. 09/989,006, filed on November 21, 2001, which is a continuation-in-part of PCT Application No. PCT/US01/27023 filed August 30, 2001, the disclosure of which is hereby expressly incorporated by reference herein.

Field of the Invention

The present invention relates to printing onto rigid substrates, and to the printing onto textured, contoured or other three-dimensional substrates. The invention is particularly related to the printing onto such substrates as those having textile fabric surfaces or molded objects, rigid panels such as office partitions, automobile interior panels and other contoured objects, and to such printing using ink jet printing techniques.

Background of the Invention

Applying ink to a substrate by ink jet printing requires a proper spacing between the ink jet nozzles and the surface of the substrate to which the printing is applied. Normally, this spacing must be set to within one or two millimeters to maintain effective printing by an ink jet process. If the distance from the nozzles to the surface being printed is too great, deviations from ideal parallel paths of the drops from different nozzles become magnified. Further, the longer the flight path of the drops from the printhead to the substrate, the more dependent the accuracy of the printing becomes on the relative speed between the printhead and the substrate. This dependency limits the rate of change in printhead-to-substrate velocity, including changes in direction. Also, the velocity of the drops moving from the printhead nozzles to the substrate declines with the

distance traveled from the nozzles, and the paths of such drops become more greatly affected by air currents and other factors with increased nozzle to substrate distance. Additionally, droplet shape changes the farther the drop moves from the nozzle, which changes the effects of the drop on the substrate. Accordingly, variations in the distance from the printhead to the substrate can cause irregular effects on the printed image.

In addition to problems in jetting ink onto contoured surfaces, the curing of UV inks requires delivery of sufficient curing energy to the ink, which is often difficult to achieve where the surface is contoured.

Further, some substrates deform, even temporarily, when heated. Deformation caused by heat may be such that, for example, the material returns to its undeformed state when it cools. Nonetheless, even temporary deformation can adversely affect the print quality if it exists when ink is being jetted onto the substrate. Where spot curing of UV inks is employed, which is performed by exposing ink to UV immediately upon its contacting the substrate, UV that is accompanied by heat producing radiation can deform substrates such as foamboard while the ink jets are making single or multiple passes over the deformed print area.

For these reasons, ink jet printing has not been successful on contoured materials and other three-dimensional substrates, particularly when printing with UV curable inks.

Summary of the Invention

An objective of the present invention is to provide for the ink jet printing onto substrates that tend to deform when heated. A particular objective of the present invention is to maintain desired printhead-to-substrate spacing when jetting ink onto rigid substrates, particularly with UV curable inks.

According to the principles of the present invention, printed images are applied to rigid substrates with printing elements that may be moveable relative to the plane of the substrate being printed. In certain embodiments, the invention provides a wide-substrate ink jet printing apparatus with printheads that move toward and away from the plane of a substrate to maintain a fixed distance between the nozzles of the printhead and the surface onto which the ink is being

jetted. The variable distance over the plane of the substrate allows a controlled and uniform distance across which the ink is jetted.

According to the invention, the printing element may include an ink jet printhead set having a plurality of heads, typically four, each for dispensing one of a set of colors onto the substrate to form a multi-colored image. To maintain the constant distance or to otherwise control the distance, one or more sensors may be provided to measure the distance from the printhead or from the printhead carriage track to the point on the substrate on which ink is to be projected. Such sensors generate reference signals that are fed to a controller that controls a servo motor on the printhead carriage. The printhead may be moveably mounted to the carriage, for example, on a ball screw mechanism, and be moveable toward and away from the plane of the substrate by operation of the servo motor. Each printhead of the set may include four different color printheads that are separately moveable relative to a common printhead carriage, and are each connected to one of a set of four servo motors by which its position relative to the plane of the substrate is capable of control relative to the positions of the other printheads. The printheads of the set may be arranged side-by-side in the transverse direction on the carriage so that one head follows the other across the width of the substrate as the carriage scans transversely across the substrate.

Each printhead has, in the preferred embodiment, a plurality of ink jet nozzles thereon for dispensing a given color of ink in a corresponding plurality of dots, for example, 128 in number, that extend in a line transverse to the carriage, which is in a longitudinal direction perpendicular to the scan direction of the carriage. Two laser or optical sensors are provided on the carriage, one on each side of the heads, so that a distance measurement of the surface to the substrate can be taken ahead of the printheads when the heads are scanning in either direction. The controller records the contour of the substrate ahead of the printheads and varies the position of each printhead, toward and away from the substrate plane, as each printhead passes over the points at which the measurements were taken, so that each of the independently moveable heads follows the contour and maintains a fixed distance from the surface being

printed. While it is preferred to adjust the position of the printhead or nozzle thereof relative to the substrate which is fixed on a printing machine frame, the substrate surface can alternatively be positioned relative to a printhead that is maintained at a fixed vertical position on the frame.

According to the preferred embodiment of the invention, UV ink is printed onto material and the cure of the ink is initiated by exposure to UV light radiated from UV curing lights mounted on the printhead carriage, one on each side of the printhead set. The lights are alternatively energized, depending on the direction of motion of the carriage across the substrate, so as to expose the printed surface immediately behind the heads. By so mounting the UV curing lights on the printhead carriage, the jetted ink can "spot cure" the ink, or to cure the ink immediately upon its contacting the substrate. Such spot curing "freezes the dots" in position and prevents their spreading on or wicking into or otherwise moving on the substrate. With certain substrates, conventional or broad spectrum UV curing lights include radiation that can heat the substrate. Such radiation includes infra-red radiation and radiation of such other wavelengths that tend to heat a particular substrate.

In the case of many rigid substrates, such as foamboard and several other of the more commonly used substrates, energy radiating from the UV light curing source onto the substrate heats the substrate enough to deform it. Such deformation can deform rapidly, with the surface of the substrate rising or rippling within seconds of exposure. Usually, this deposition is temporary in that the substrate blisters or swells when heated but returns to its original condition immediately upon cooling. Where the UV exposure is carried out downstream of the printhead carriage, usually no harm results.

In the case of spot curing, the UV exposure occurs close to the point of printing. Deformation of the substrate surface that occurs due to heat in spot curing can extend to the portion of the substrate that is still to be printed, thereby changing the printhead-to-substrate spacing and adversely affecting the quality of the ink jet printing operation.

The present invention provides the use of cold UV sources for spot curing of UV curable ink on heat sensitive rigid substrates. Heat caused deformation

of the substrate in the region of the printing operation is prevented with the use of a cold UV source, Such a cold UV source can, for example, be a limited bandwidth UV source, to limit energy of wavelengths that are not effective to cure the ink from otherwise striking and heating the substrate. This can be carried out with selective bandwidth sources or with the use of filters to remove energy of undesired wavelengths. Alternatively, heat removal can be employed to remove the heat that is produced by the curing radiation. The cold UV source is useful for printing onto substrates that can deform, even temporarily, when heated, and is particularly useful where spot curing of the ink can otherwise result in the deformation of the material on which printing is still to take place.

Deformation at the printing site, even if temporary such that the material returns to its undeformed state when it cools, adversely affects the print quality because spot curing deforms the substrate as the ink jets are making single or multiple passes over the print area. This is particularly the case when printing onto foamboards that make up the largest application of printing onto rigid substrates. Such deformation of the board from heat during printing would force adjustment of the head height above the deformation zone. Higher head height usually results in poorer print quality. With a cold-UV spot-cure ink-jet system, the head-to-substrate distance can be minimized to maximize print quality.

In prior practice, spot curing has not been used to ink jet print onto rigid substrates, except as proposed by applicants. Cold UV is known for curing UV ink downstream of a printing station to prevent permanent deformation to or buring of the substrate. Temporary deformation that will disappear after the substrate cools has not been a problem in the prior art. Such deformation is likely to be a problem where slight raising or warping of the surface takes place as ink is being jetted onto the substrate, which can occur during spot curing.

When printing onto contoured material, the distance from the printheads to the substrate where the ink is to be deposited can be determined by measuring the distance from a sensor to the substrate ahead of the printheads and mapping the location of the surface. For bidirectional printheads that move transversely across the longitudinally advancing fabric, providing two distance measuring sensors, one on each of the opposite sides of the printheads, are

provided to measure the distance to the contoured fabric surface when the printheads are moving in either direction. For some inks and for sufficiently rigid materials, a mechanical rolling sensor may be used, for example, by providing a pair of rollers, with one roller ahead of, and one head behind, the printhead so that the average distance between the two rollers and a reference point on the printhead can be used to control the distance of the printhead from the plane of the substrate. To achieve this, one or more printheads can be mounted to a carriage having the rollers on the ends thereof so that the mechanical link between the rollers moves the printhead relative to the plane of the substrate. In most cases, a non-contact sensor, such as a laser or photo eye sensor, is preferred in lieu of each roller. The outputs of two sensors on opposite sides of the printheads can be communicated to a processor, to measure the distance from the heads to the fabric ahead of the bidirectional heads, to drive a servo motor connected to the printhead to raise and lower the head relative to the substrate plane so that the printheads move parallel to the contoured surface and jet ink onto the fabric across a fixed distance.

These and other objects of the present invention will be more readily apparent from the following detailed description of the preferred embodiments of the invention.

Brief Description of the Drawings

Fig. 1 is a perspective view of one embodiment of an apparatus embodying principles of the present invention.

Fig. 2 is a partial cross-sectional view along line **2-2** of **Fig. 1** showing structure for maintaining printhead-to-substrate distance on a contoured substrate.

Fig. 3 is a perspective view of the printhead carriage of the apparatus of **Fig. 1**.

Fig. 4 is a cross-sectional view through the UV curing head of the printhead carriage of **Fig. 3**.

Detailed Description of the Preferred Embodiment

Ink jet printing onto large rigid substrates is described in the commonly assigned and copending U.S. Patent Applications Serial Nos. 09/650,596, filed

August 30, 2000, and 09/822,795, filed March 30, 2001, hereby expressly incorporated by reference herein. Ink jet printing onto large substrates, particularly textiles, is described in the commonly assigned and copending U.S. Patent Applications Serial No. 09/390,571, filed September 3, 1999, Serial No. 09/823,268, filed March 30, 2001 and Serial No. 09/824,517, filed April 2, 2001, and International Application Serial No. PCT/US00/24226, filed September 1, 2000, each hereby expressly incorporated by reference herein.

Fig. 1 illustrates an ink jet printing machine 100 for printing onto wide rigid substrates. The machine 100 includes a stationary frame 111 with a longitudinal extent represented by an arrow 112 and a transverse extent represented by an arrow 113. The machine 100 has a front end 114 into which the rigid panel 15 may be loaded onto a belt 121 of a conveyor system 120 having one or more flights which carry the panel 15 longitudinally through the machine 100. The belt 121 of the conveyor system 120 extends across the width of the frame 111 and rests on a smooth stainless steel vacuum table 105, which has therein an array of upwardly facing vacuum holes 106 which communicate with the underside of the belt 121. The belt 121 is sufficiently porous that the vacuum from the table 105 communicates through the belt 121 to the underside of the rigid panel 15 to assist gravity in holding the panel 15 in place against the top side of the belt 121. Preferably, the belt 121 has a high friction rubber-like surface 108 to help prevent a horizontal sliding of a panel resting on it, through which an array of holes 109 or open mesh is provided to facilitate communication of the vacuum from the table 105 to the substrate.

The top surface of the belt 121 of the conveyor 120 is such that it provides sufficient friction between it and the underside of the panel 15 to keep the panel 15 from sliding horizontally on the conveyor 120. The conveyor 120 is further sufficiently non-elastic so that it can be precisely advanced. To this end, the belt 121 has a non-elastic open weave backing 107 to provide dimensional stability to the belt while allowing the vacuum to be communicated between the holes 106 of the table 105 and the holes 109 or open mesh in the surface of the belt 121.

The forward motion of the panel 15 on the frame 111 is precisely controllable by indexing of the belt 121 by control of a servo drive motor 122 with signals from the controller 35. The belt 121 thereby retains the panels 15 in a precisely known longitudinal position on the belt 121 so as to carry the panels 15 through the longitudinal extent of the machine 100. Such indexing of the belt 121 should be controllable to an accuracy of about 0.0005 inches where used to move the panel 15 relative to a printhead on a fixed bridge (which embodiment is not shown). In the machine 100 illustrated in **Fig. 1**, the longitudinal movement of the belt 121 of the conveyor 120 is controlled by the conveyor drive 122 to move the panel into printing position and then to advance it downstream after it is printed. One or more additional separately controllable drives 132 may be provided to control the downstream flights, if any, of the conveyor 120.

Along the length of travel of the conveyor 120 may be provided two or more stations, including an ink jet printing station 125 and one or more curing or drying stations, which may include UV light curing stations 124 and/or a heating station 126. The printing station 125 includes a bridge 128. Where the belt 121 is operable to precisely index the panel 15 relative to the bridge 128, the bridge may be fixed to the frame 111 and extend transversely across it. A printhead carriage 129 is transversely moveable across the bridge 128 and has one or more sets 130 of ink jet printing heads thereon. The carriage 129 is preferably fixed to the armature of a linear servo motor 131 which has a linear array of stator magnets extending transversely across the bridge 128, so that the carriage 129 is transversely moveable across the bridge 128 by positioning and drive control signals sent to the servo 131 by the controller 35, described above.

In the illustrated embodiment, the bridge 128 is mounted to the moveable armatures 133a,134a that ride on longitudinal tracks 133b,134b of linear servo motors 133,134 at each side of the conveyor 120. Once a panel 15 is positioned under the bridge 128 by movement of the belt 121, the bridge 128 is indexed in the longitudinal direction as transverse bands of an image are printed in successive scans of printheads 130, described below. This indexing should be as accurate as needed to insure that the scans register one with another and

can be interlaced, as required, to produce the desired print quality and resolution. Such accuracy is preferred to be about 0.0005 inches. Lower resolution, and thus less accuracy, is acceptable for printing on textile surfaces rather than on smoother surfaces such as vinyl.

Fig. 2 illustrates a set 130 of four ink jet printing heads 130a-130d configured to respectively apply the four colors of a CMYK color set. The ink jet printing heads 130a-d each include a linear array of one hundred twenty-eight (128) ink jet nozzles that extend in the longitudinal direction relative to the frame 111 and in a line perpendicular to the direction of travel of the carriage 129 on the bridge 128. The nozzles of each of the heads 130 are configured and controlled to simultaneously but selectively jet UV ink of one of the CMYK colors side-by-side across the substrate 15, and to do so in a series of cycles as the nozzles scan the substrate 15. The heads 130a-d of a set are arranged side-by-side to print consecutively across the same area of the substrate 15 as the carriage 129 moves across the bridge 128, each depositing one of the four colors sequentially on each dot position across the substrate 15.

Each of the heads 130a-d is moveably mounted to the carriage to individually move vertically or perpendicular to the plane of the substrate 15. The distance of each head 130a-d from the plane of the substrate 15 is controlled by a respective one of a set of servos 137a-d mounted to the carriage 129 to follow one behind the other over the same contour of the substrate 15. The servos 137a-d are responsive to signals from the controller 35 which control the positions of the heads 130a-d to maintain each a controlled distance from the surface of the substrate 15 where the surface 16 of the substrate 15 is contoured.

Usually, it is desirable to maintain the heads a fixed distance from the surface 16 on which they are to print. This is achieved by providing optical sensors 138a,138b on the opposite transverse sides of the carriage 129. The printhead set 130 is bidirectional and prints whether moving to the right or to the left. As the printhead carriage 129 moves on the bridge 128, the leading one of the sensors 138a or 138b measures the distance from the sensor 138 and the surface 16 of the substrate 15 at a point directly in line with, typically directly

below, the sensor 138. This measurement is communicated to the controller 35, which records the measured distance and the coordinates on the surface 16 of the substrate 15 at which the measurement was taken. These coordinates need only include the transverse position on the substrate 15 where the information is to be used in the same pass or scan of the carriage in which the measurement was taken. However, the controller 35 may also record the longitudinal coordinate by taking into account the position of the panel 15 on the frame 111 relative to the bridge 128.

In response to the measurements, the controller 35 controls the servos 137 to vertically position the each of the heads 130 to a predetermined distance from the contoured surface 16 of the substrate 15 as the respective head arrives at the transverse coordinate on the substrate 15 at which each measurement was taken. As a result, the nearest of the heads 130 to the leading sensor 138, which are spaced a distance *B* from the sensor 138, follows the contour of the fabric at a delay of *V/B* seconds after a given measurement was taken, where *V* is the velocity of the carriage 129 on the bridge 128. Similarly, the heads 130 are spaced apart a distance *A* and will each sequentially follow the same contour as the first head at *V/A* seconds after the preceding head.

The extent of the heads 130 in the longitudinal direction determines the accuracy with which the heads can follow the contours of the substrate 15. Greater accuracy can be maintained, and more variable contours can be followed, by using narrower heads, for example, of 64 or 32 jets per head in the longitudinal direction. Accordingly, multiple sets of heads 130 can be arranged in a rectangular or other array on the carriage 129, with heads of the different sets being arranged side-by-side across the carriage 129 in the longitudinal direction of the substrate 15 and frame 111. For example, two sets of heads having 64 jets per head each or four sets of heads having 32 jets per head each will produce the same 128 dot wide scan, but with greater ability to maintain spacing from head to substrate where the contours vary in the longitudinal direction on the substrate 15.

Printing on rigid panels, even where the surface is not textured or contoured, can benefit from the sensing and adjustment of the distance from print nozzle to surface of the panel since the rigid frame of the panel and the thickness of the panel when supported on the frame of a printing apparatus makes the position of the upper surface of the panel unpredictable.

Where UV curable ink is used, the UV curing station 124 is provided as illustrated in **Fig. 1**. It may include a UV curing head 23 transversely moveable independently of the printheads 130 across the downstream side of the bridge 128 or otherwise located downstream of the printing station 125, and/or may include UV light curing heads 123a and 123b mounted on the carriage 129.

Where employed to separately move across the substrate, the curing head 23 is preferably intelligently controlled by the controller 35 to selectively operate and quickly move across areas having no printing and to scan only the printed images with UV light at a rate sufficiently slow to UV cure the ink, thereby avoiding wasting time and UV energy scanning unprinted areas. If the head 23 is included in the printing station 25 and is coupled to move with the printheads 30, UV curing light can be used in synchronism with the dispensing of the ink immediately following the dispensing of the ink.

Where UV curing heads are employed on the carriage 129, as the carriage 129 moves transversely on the bridge 128, only the curing head 123a,123b that trails the printheads 130 is operated so that the UV light exposes ink after its deposition onto the substrate 15. Such carriage mounting of the curing heads 123a,123b enables the freezing of the dots of ink where they are deposited, reducing drop spread and wicking of the ink. The curing heads 123a,123b may also be moveable toward and away from the plane of the substrate 15 in the same manner as the printheads 130a-d, controllable by servos 139a,139b, respectively, to maintain their spacing from the surface 16, as illustrated in **Fig. 2**.

Effective curing of UV ink requires that the UV light be either parallel beam light, have a long depth of field, or be more precisely focused on the surface bearing the ink. Precise focus is more energy efficient, in which case, moving the UV heads 123a,123b to maintain a constant spacing from the

surface 16 maintains the focus of the curing UV light. UV light curing heads are typically configured to sharply focus a narrow, longitudinally extending beam of UV light onto the printed surface. Therefore, instead of physically moving the UV light curing heads or sources 123a,123b, the focal lengths of the light curing heads 123a,123b may be varied to follow the contours of the substrate 15. The light curing head 123, where used, may similarly be configured to move perpendicular to the surface 16 of the substrate 15.

Further, in accordance with the preferred embodiment of the invention, the UV curing heads, particularly when mounted on the carriage, are cold-UV light, which, through the use of filters or narrow bandwidth radiation, avoid heating a substrate 15. This is particularly useful where the apparatus 100 is to be used for printing onto heat sensitive substrates such as foamboard. Where carriage mounted UV curing heads 123a,123b are used and the freezing of the dots at the point of jetting is desired, deforming the substrate at the location where the ink drops are being deposited would degrade the printed image. Such cold-UV curing light systems use cold mirrors, infrared cut filters, and water cooled UV curing to keep the temperature of the substrate low, avoiding substrate deformation.

Fig. 3 illustrates the details of an arrangement of the carriage 129 on which cold UV curing heads 150 are used in place of the heads 123a,123b described above. A head of the type 150 may also be used in place of the separate curing head 123 described above. Such UV heads 150 in the embodiment illustrated are fixed, rather than vertically moveable, and emit parallel UV light rather than focused light. The heads 150 each include a ten inch linear bulb 151 approximately one inch in diameter located at the focal point of a downwardly facing ten inch linear reflector 152 having a lower surface 153 having a generally parabolic cross section as illustrated in **Fig. 4**. The reflector 152 is formed of extruded aluminum and has a pair of cooling fluid return channels 153 formed therein that run the length thereof. Extending the length of the head 150 and positioned directly below the bulb 151 is a hollow UV transparent tube 155 which may be formed of a temperature and radiation tolerant material, for example, quartz. The tube 155 has a fluid 156, for

example, de-ionized water, flowing therein. The tube is connected in a circuit with the cooling channels 153 and a recirculating pump 157 so that the cooling fluid 156 flows through the tube 155, where it absorbs approximately 80-85% of the infrared energy passing therethough, while only absorbing about 6-8% of the UV light, and then through the channels 153 further pick up heat from the wall of the reflector 152. Before flowing to the pump 157, the fluid from the channels 153 flows through a heat exchanger 158 where it is cooled. The bulbs 151 consume approximately 125 to 200 watts per linear inch, but may be operated at different power levels. Assemblies suitable for the heads 150 are available from Printing Research, Inc., Dallas, Texas, www.superblue.net. In operation, UV light is emitted from the bulbs 151 along with radiant energy of other wavelengths, such as infrared light, that would result in the heating of the substrate 15. Such radiant energy of these other wavelengths is, however, mostly absorbed in the fluid 156 and removed before impinging on the substrate 15. As a result, no thermal distortion, even of a temporary nature, occurs at the surface 16 of the substrate 15.

The heat curing or drying station 126 may be fixed to the frame 111 downstream of the printing station 125 and the UV light curing station, if any, may be located off-line. Such a drying station 126 may be used to dry solvent based inks with heated air, radiation or other heating techniques. It may also be used to further cure or dry UV inks.

The heat curing or drying station 26 may be fixed to the frame 11 downstream of the UV light curing station or may be located off-line. With 97% UV cure, the ink will be sufficiently colorfast so as to permit the drying station to be off-line. When on-line, the drying station should extend sufficiently along the length of fabric to adequately cure the printed ink at the rate that the fabric is printed. When located off-line, the heat curing station can operate at a different rate than the rate of printing. Heat cure at the oven or drying station 26 maintains the ink on the fabric at about 300°F for up to three minutes. Heating of from 30 seconds to three minutes is the anticipated advantageous range. Heating by forced hot air is preferred, although other heat sources, such as

infrared heaters, can be used as long as they adequately penetrate the fabric to the depth of the ink.

The above description is representative of certain preferred embodiments of the invention. Those skilled in the art will appreciate that various changes and additions may be made to the embodiments described above without departing from the principles of the present invention. Therefore, the following is claimed: